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Small-Group Activity to Reinforce the Impact of Valvular Defects and Heart Failure on Cardiac Pressure-Volume Relationships

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Citation: Hopper M, Tune J, Klabunde R. Small-group activity to reinforce the impact of valvular defects and heart failure on cardiac pressure-volume relationships. *MedEdPORTAL*. 2018;14:10675. https://doi.org/10.15766/mep_2374-8265.10675

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Appendices

A. Student Handout.docx
B. Facilitator's Guide.docx
C. Animated PowerPoint.pptx

All appendices are peer reviewed as integral parts of the Original Publication.

Abstract

Introduction: An important topic in cardiac physiology is the relationship between changes in intracardiac pressures and volumes during the cardiac cycle. This topic lends itself well to utilizing active learning principles to facilitate student understanding of pressure and volume changes in normal cardiac physiology and in the pathophysiology of valve disease and heart failure. We describe an active learning exercise regarding this topic that engages and facilitates student learning in a small-group setting. **Methods:** Following an overview lecture on the normal cardiac physiology, small groups of students under the guidance of a facilitator were provided with a worksheet consisting of questions related to background knowledge of cardiac physiology. Additional questions related to five valve disease and heart failure cases were also provided to promote the application of basic physiology principles to clinically relevant problems. The facilitator was provided with a guide to help facilitate the student interactions. Following the group worksheet activity, an animated slide presentation was shown to further engage student learning through active discussion of their worksheet answers. **Results:** Students were assessed by written examination, and were found to have a higher performance on the subset of questions related to this learning activity compared to the overall exam. Of the 175 students completing the exercise, 23 voluntarily provided feedback via a survey. Student surveys provided overwhelmingly positive feedback on the benefits of this active learning exercise. **Discussion:** Small group, active learning exercises benefited student learning by providing a framework for analysis, synthesis, and application of clinically relevant cardiac physiology concepts.

Keywords

Active Learning, Echocardiogram, Cardiac Physiology, Cardiac Cycle, Ventricular Pressure-Volume Relationship, Valve Disease, Systolic Dysfunction, Pulmonary Capillary Wedge Pressure

Educational Objectives

Following completion of the active learning session, students will be able to:

1. Describe the basic principles of echocardiography and how this technology is utilized clinically.
2. Illustrate systolic and diastolic pressures in the right atrium, right ventricle, and pulmonary artery.
3. Demonstrate how a Swan-Ganz catheter is used to assess pulmonary capillary wedge pressure.
4. Explain the normal relationship between left ventricular pressure and volume and define where each phase of the cardiac cycle occurs in this relationship.
5. Draw left ventricular pressure-volume relationships and determine pulse pressure, mean arterial pressure, and ejection fraction from provided data.
6. Explain how valvular defects and congestive heart failure influence the relationship between left ventricular pressure and volume.

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Introduction

In the 2016-2017 academic year, the Indiana University School of Medicine implemented a renewed curriculum. The new curriculum required at least 50% of all course contact time be dedicated to nondidactic active learning exercises. This requirement was based primarily on the Liaison Committee on Medical Education standards in effect during the planning of the revised curriculum.[1] Specifically, these requirements were introduced to address standard ED-5-A: “A medical education program must include instructional opportunities for active learning and independent study to foster skills necessary for lifelong learning.” Under this new curriculum, physiology content was divided into units to be taught in a number of new courses in the first and second years of medical school. New courses included a fundamentals of health and disease (FHD) course for first-year medical students and a series of five systems-based courses to be offered to second-year students.

The FHD course was scheduled with 2 hours of active learning following each 2 hours of lecture. A systematic approach to active learning, such as problem-based learning, or team-based learning, was not universally adopted. Instead, faculty were encouraged to develop active learning exercises requiring students to work collaboratively within small groups,[2] and to engage students in application of higher-order skills such as analysis, synthesis, and application.[3] One of the FHD small-group exercises is the cardiovascular pressure-volume loop exercise described here. This exercise engaged students in plotting both normal and abnormal pressure-volume loops and was particularly effective as indicated by student evaluations and exam performance. This 2-hour active learning session followed a 2-hour lecture focused on cardiac muscle and whole heart mechanics. The preceding didactic session introduced students to a number of important concepts to be further explored in the nondidactic active learning session. Such concepts included: preload, end diastolic volume, afterload, end systolic volume, contractility, compliance, echocardiography, normal atrial and ventricular pressures during systole and diastole, and general functions of pressure-volume loops.

Although others have published pressure-volume loop simulations, such offerings fail to engage the learner in constructing new knowledge for themselves.[4] Additionally, case-based studies commonly require students to apply their understanding of pressure-volume loops, but assume the learner has complete and correct understanding of this important foundational concept. Based on previous student exam performance, the authors have observed that students often lack this appropriate level of understanding. Therefore, to improve learning outcomes, this exercise engaged students in constructing pressure-volume loops based on data, and then required students to apply understanding of pressure-volume loops in the diagnosis of disease.

This exercise is unique in that students have the opportunity to work cooperatively in small groups and to build a product as they review lecture notes and plot loops. This type of group interaction requires elaboration and discussion, which has been shown to foster conceptual understanding.[2,5] Previously published work demonstrates that group discussion aids in retention, promotes reorganization, increases awareness of erroneous reasoning, and assists students in identifying gaps in personal knowledge.[6,7] Exam-style questions included in the exercise also provides an opportunity for retrieval practice and formative feedback for students.[8] Based upon student evaluation and exam performance, the following exercise met its objectives as it engaged students in synthesizing, evaluating, and applying information critical to understanding of pressure-volume loops.

Methods

The worksheet provided to the students (Appendix A) consisted of four questions related to necessary background knowledge followed by five case-based learning activities. Three of the questions dealt specifically with: (1) basic principles of echocardiography and how this tool is used to assess valvular disorders, (2) recognizing differences in systolic and diastolic pressure as a Swan-Ganz catheter passes through the right atrium, right ventricle, pulmonary artery, and how wedge pressure is determined, and (3) understanding of how the events of the cardiac cycle relate to the left ventricular pressure-volume relationship.

The five cases provided students with identical tasks/questions in which they are asked to draw left ventricular pressure-volume loops from data provided by the echocardiography and Swan-Ganz catheter placement; determine pulse pressure, mean arterial pressure, and ejection fraction; predict whether (and when) they would anticipate hearing a murmur; and provide a likely diagnosis. It should be recognized that the purpose of this exercise was not to recapitulate clinical practice (as this is clearly not the case) but to have students interpret provided data to improve their understanding of the relationship between left ventricular pressure and volume throughout the cardiac cycle, and then to apply their understanding to how valve disorders (stenosis, insufficiency) and ventricular systolic failure influenced these key variables. It is important for facilitators to recognize and point out to students that data for precise valvular closure are not included.

For this active learning experience, students were placed in groups of approximately six to eight students and asked to complete the entire exercise. Students were encouraged to work together within their groups to plot the pressure-volume loops for each of the cases and to answer all of the questions provided. As the medical school is distributed across multiple campus centers, class size varied between 24 and 150 students, with all students in each class completing the exercise at the same time. The group activity took around 60 minutes for the students to complete, including about 5 minutes for introduction to the activity. This exercise required classroom space appropriate for a small-group activity, as well as a projection system for reviewing the provided PowerPoint presentation.

After the students complete the questions, the facilitators used the second half of the 2-hour time period to discuss each question and answer with the students. In particular, the first 10 minutes of the discussion portion of the class was used to discuss echocardiography, pressure measurements with Swan-Ganz catheter, and basic events of the cardiac cycle of the pressure-volume relationship. The following 50 minutes of class time was used to cover each of the five cases, spending approximately 10 minutes per case. The facilitator's guide in Appendix B provides detailed answers to each of the questions on the student worksheet.

Appendix C contains an animated PowerPoint presentation, which is to be used by course instructors during the discussion portion of the active learning session (i.e., after each of the student groups has completed the exercise.) This file contains detailed answers to each of the questions on the student worksheet in presentation format. Facilitators were encouraged to seek input from different groups of students for each of the answers and feedback from other groups as to whether they agreed, disagreed, or had any additional thoughts as appropriate. This file may be provided to the students following completion of the exercise.

Results

Exam Results

Student understanding of the cardiovascular concepts covered in this activity, and its preceding lecture, was assessed using an instructor written exam administered at the end of a 2-week block that covered both respiratory and cardiovascular concepts. The 100-question exam included 54 cardiovascular and 46 respiratory system questions. All exam scores were recorded and used for grading purposes. Study design included internal control comparing test-item performance between activity related questions (mapped questions) and other cardiovascular test questions. Of the 54 cardiovascular questions, 11 questions were mapped to concepts covered in this exercise. Although exam questions are part of a secure student test bank (and cannot be shared), sample questions relevant to the content include the following:

Question one: The pressure and volume changes noted in the following pressure-volume loop (shaded loop; Figure) represent which of the following valve defects? Answer options included: (A) aortic stenosis, (B) aortic regurgitation, (C) mitral regurgitation, and (D) and mitral stenosis. For this question the correct response was (C) mitral regurgitation, as this causes ventricular dilation and loss of true isovolumetric phases because the mitral valve is always open. Dilation occurs because increased left atrial pressure enhances ventricular filling, thereby promoting dilation (increased end-diastolic volume). Peak systolic pressure, and aortic systolic pressure, will be lower (as shown) if the stroke volume into the aorta is reduced because of the backward flow into the left atrium during ventricular systole.

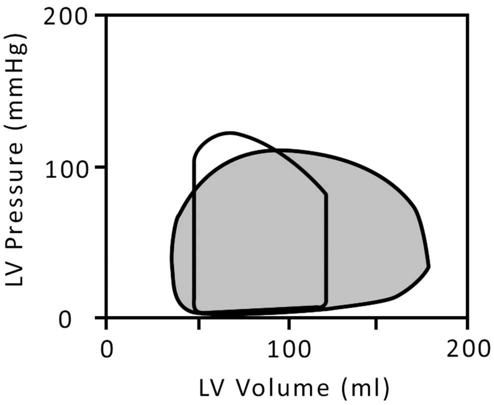

Figure. Peak systolic pressure and aortic systolic pressure will be lower if the stroke volume into the aorta is reduced because of the backward flow into the left atrium during ventricular systole. Image owned by Richard Klabunde, used with permission.

Question two: Based on the cardiopulmonary pressure and volume data (Table 1), what is the most likely diagnosis? Answer options included: (A) aortic valve stenosis, (B) mitral valve stenosis, (C) mitral valve insufficiency, (D) pulmonic valve stenosis, and (E) tricuspid valve stenosis. For this question the correct answer was (A) aortic valve stenosis, because during systole, there is a large pressure gradient between the left ventricle and aorta, which indicates high outflow resistance and aortic valve stenosis. Because blood backs up proximal to the left ventricle, those proximal pressures (e.g., pulmonary capillary wedge press, pulmonary artery pressure) are increased.

Table 1. Data for Question two

Pressure/Volume	Value
Aortic pressure (sys/dias)	115/80
Left ventricular press (sys/dias)	165/20
Pulmonary capillary wedge press (mean)	20
Pulmonary artery pressure (sys/dias)	45/25
Right ventricular press (sys/dias)	45/5
Right atrial pressure (mean)	5
LV End-diastolic volume (ml)	120
LV End-systolic volume (ml)	60

Abbreviations: Sys, systolic; dias, diastolic.

Question three: A patient is diagnosed with moderately severe aortic valve regurgitation. In the absence of ventricular failure, which of the following changes is associated with this valve defect? Possible answers included: (A) left ventricular preload decreases, (B) aortic systolic pressure is decreased, (C) aortic diastolic pressure is increased, and (D) left ventricular ejection volume into the aorta is increased. For this question the correct answer was (D) left ventricular ejection volume into the aorta is increased, because in this condition, blood regurgitates from the aortic back into the ventricle whenever left ventricular pressure is less than aortic pressure, left ventricular preload (end-diastolic volume) is increased and aortic diastolic pressure is decreased. The increased preload activates the Frank-Starling mechanism to increase stroke volume into the aorta, which can increase aortic systolic pressure. However, the net stroke volume (ejected volume minus backward flow volume) is reduced.

Overall, student performance on the cardiovascular section of the exam was 70%. Students averaged a 79% correct response rate on the 11 mapped questions. These data indicate that student understanding of concepts covered in this exercise exceeded their general understanding of other cardiovascular concepts covered in the FHD course. Each of the 11 questions demonstrated an acceptable point biserial (range .22 to .33) and therefore were included in our analysis.

Survey Feedback

Following completion of the exercise, 23 of the 175 students who completed the exercise volunteered to anonymously complete an evaluative survey. The survey included two Likert- scale questions related to their understanding of the material, and three open-ended questions (Table 2). Likert scale averages of 3.82 and 3.86, on a 4.0 scale (1 = *Strongly Disagree* 4 = *Strongly Agree)* indicated students overwhelmingly agreed the exercise was effective in enhancing understanding of key concepts. Not a single student selected *disagree* or *strongly disagree* for either of the Likert scale questions.

Table 2. Student Focus Group Survey Results (*N* = 23)

Item	*M*[a]
This exercise enhanced my understanding of how cardiac pressures and volumes change during the cardiac cycle (systole/diastole).	3.82
This exercise enhanced my understanding of pressure-volume relationships in the diseased heart.	3.86

[a]Four-point Likert scale (1 = *Strongly Disagree*, 4 = *Strongly Agree*).

Student responses to open-ended questions were also overwhelmingly positive. Students shared more positive than negative comments in response to the question “What did you find most helpful?” Many students simply wrote that plotting, or visualization was an effective learning strategy. Others were more specific and included comments such as the following:

- “Gave a clinical perspective and information that I felt would be very relevant on future practice (allowed me to be more engaged).”
- “Working through the different disease conditions with visual graphs really gave me a deeper understanding of the physiologic mechanisms.”
- “The visual plotting we did helped me make connections between variables that might otherwise have been unintuitive. I like the variety of cases as well.”

A number of students reported a lack of clear written instructions. Although students received brief orientation and oral instructions at the beginning of the session (see Appendix B), it appears that written instructions would be helpful to the students. Updates to the instructions and learning objectives are provided in the appendices.

As typical for this population, many students wanted more clinically relevant information and asked for additional disease states and how diseases would be treated. One student also asked for incorporation of the electrocardiogram. While these were good suggestions, the FHD course was an introductory course, and thus much of this material would be covered later in a second-year cardiovascular course. For example, electrocardiogram was intentionally omitted for the learning objectives for FHD and placed in the second year.

A number of students commented that they left the session wanting more of this type of exercise, as they felt it was helpful and wanted more practice questions like these to use. The primary issue with including more cases relates to time constraints, as we only have 2 hours for this entire exercise.

Discussion

This active learning exercise was designed to facilitate student understanding of pressure and volume changes in normal cardiac physiology and in the pathophysiology of valve disease and heart failure. As evidenced by both student surveys and performance on mapped exam questions related to this exercise, this exercise was highly effective in meeting the objectives and reinforcing key concepts related to the cardiac cycle and mechanics in a clinically relevant manner. Although the authors understand that echocardiography and Swan-Ganz catheters are not specifically utilized as described in this exercise (i.e., to generate pressure-volume relationships), we found that introducing these approaches provided the opportunity to illustrate how ventricular volumes, cardiac output, and pressures are determined in the clinical setting. However, it should be noted that such data are not used clinically to generate pressure-volume relationships for individual patients per se. This introduction, along with incorporation of the impact of valvular defects on ventricular pressure-volume relationships, provides a unique way to facilitate student learning of key cardiovascular concepts.

The exercise was based on images and text from Dr. Klabunde's textbook[9] and website.[10] Students were advised to use these as reference during the exercise. Students worked cooperatively in groups to complete the exercise, with facilitators available to answer questions. During the last 20 minutes of the session, a wrap-up was conducted to summarize the cases. The animated PowerPoint was used to reveal solutions, but only after engaging students in elaborating on their work. Students were then asked to share their conclusions and explain their thinking. Overall there were no major difficulties noted with this process, and many students commented how much they enjoyed the exercise. However, one aspect we found that should be reinforced with students is that they do not need to indicate on the pressure-volume relationships where each valve opens or closes, as such measures are not routinely provided clinically and are not necessary for diagnosis of any of the cases. Furthermore, recognition of the loss of isovolumetric time periods of the cardiac cycle with aortic and mitral insufficiency is likely to be missed by a majority of students. Thus, additional explanation of the pathophysiology behind this consequence of valvular insufficiency is likely to be necessary (see comments in Appendix B and C).

This exercise provided an effective means to engage students in work that enhanced their understanding of pressure-volume loops. Additionally, exam performance indicated that participants achieved the level of foundational understanding required to use Bloom's higher-order skills (evaluate, analyze, and think critically) when answering exam questions. With changes to pressure-volume loop data each year, this exercise will continue to be used with future students. The authors may also consider adding a pre- and posttest to assess learning outcomes and provide formative feedback to students.

Development of small-group activities such as this provides faculty the opportunity to actively engage their students without universally subscribing to methodologies such as problem-based learning or team-based learning. As this exercise required no specialized equipment or facility, faculty can easily adapt this exercise to match their personal preferences, student characteristics, as well as time and space constraints.

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Disclosures
None to report.

Funding/Support
None to report.

Ethical Approval
This publication contains data obtained from human subjects and received ethical approval.

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Received: July 24, 2017 | **Accepted:** January 21, 2018 | **Published:** February 6, 2018